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**PRE-COLLEGE STUDENTS CONTRIBUTE TO THE  
CASSINI-JUPITER MILLENNIUM FLYBY**

M. J. Klein  
Jet Propulsion Laboratory/Caltech

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## **PRE-COLLEGE STUDENTS CONTRIBUTE TO THE CASSINI-JUPITER MILLENNIUM FLYBY**

M. J. Klein, S. J. Bolton, S. Gulkis, M. A. Janssen and S. M. Levin  
Jet Propulsion Laboratory / Caltech  
Pasadena CA 91109

J. P. Roller and R. K. McLeod  
Lewis Center for Educational Research  
Apple Valley, CA 92307

### **Abstract**

The Cassini-Jupiter Microwave Observing Campaign (Cassini-JMOC) was a coordinated series of space-based and ground-based microwave observations of Jupiter conducted during the flyby of the Cassini spacecraft from November 2000 through March 2001. The centerpiece of the campaign was the high resolution mapping of 2.2 cm synchrotron radio emission from Jovian radiation belts made with a passive microwave radiometer that was built into the Cassini Radar Instrument. This paper reports supporting ground-based C-JMOC observations made with NASA's Deep Space Network (DSN) antennas at Goldstone, California. Precision measurements of Jupiter's flux density were made at the spacecraft frequency (2.2 cm wavelength) to improve the calibration. Observations were also made at longer wavelengths (3.5 cm and 13 cm) to monitor the time variability of the synchrotron emission from the Jovian radiation belts. Cassini-JMOC included an educational component which allowed middle-school and high-school students to participate in the ground-based observations and data analysis. A large percentage of the Goldstone observations were conducted by students from classrooms across the nation. The students and their teachers are participants in the Goldstone-Apple Valley Radio Telescope (GAVRT) science education project, which is a partnership involving NASA, the Jet Propulsion Laboratory and the Lewis Center for Educational Research (LCER) in Apple Valley, Calif. Working with the Lewis Center over the Internet, GAVRT students conduct remotely controlled radio astronomy observations using 34-m antennas at Goldstone.

**Introduction:** The flyby of the Cassini spacecraft past Jupiter the end of December 2000 provided a unique opportunity to study Jupiter's radiation belts with high spatial resolution using a passive microwave radiometer that was built into the Cassini Radar Instrument. In a coordinated series of space-based and ground-based observations, named the Cassini-Jupiter Microwave Observing Campaign (Cassini-JMOC), Jupiter was observed at radio

wavelengths during the Cassini encounter from November 2000 through March 2001.

Cassini-JMOC has two objectives: (1) use the Cassini radar receiver to map Jupiter's synchrotron emission at a frequency above 10 GHz and thereby derive the spatial distribution of very high energy electrons (>40 MeV) for the first time; (2) conduct ground-based observations to achieve in-flight calibrations of the Cassini radar receiver

and thereby enhance the Cassini science at Saturn and Titan. In addition to the scientific objectives, the project included an educational component that allowed middle-school and high-school students to participate in the ground-based observations and data analysis.

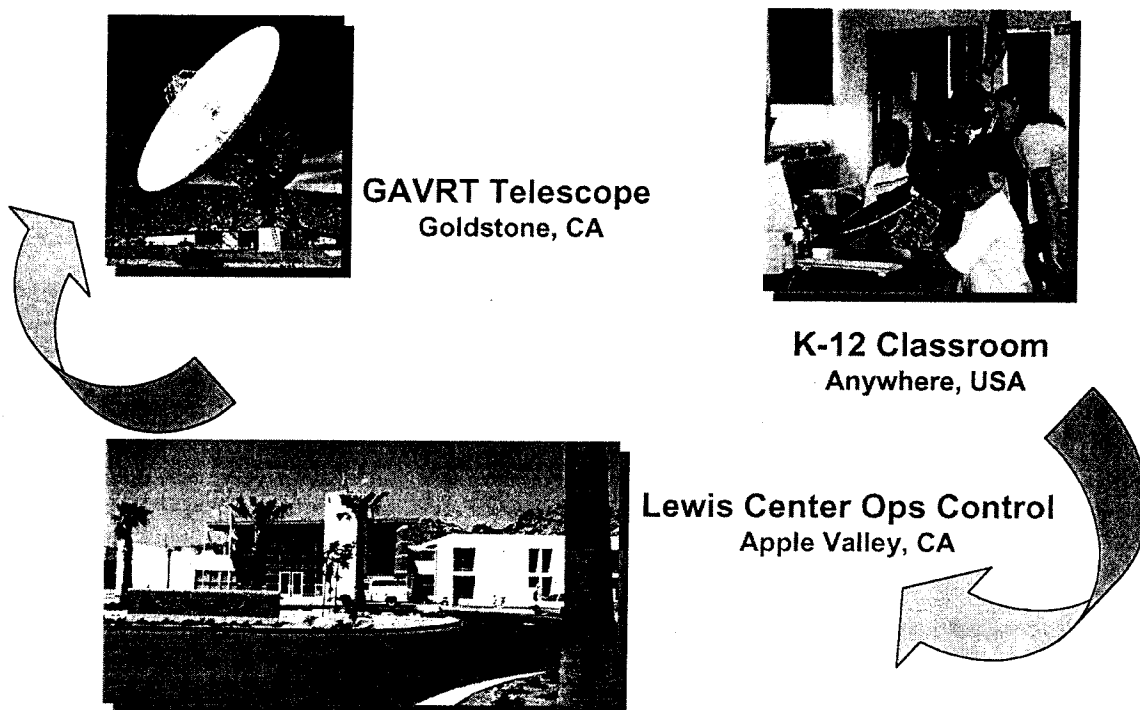
This paper reports the C-JMOC observations supported by NASA's Deep Space Network (DSN) antennas at Goldstone, California. Calibrated measurements of Jupiter's flux density relative to Venus and to a selection of radio sources were made in order to derive an accurate flux density for Jupiter at the spacecraft frequency (13.780 GHz). Precision measurements were also made at 2.3 GHz to monitor the time variability of the synchrotron emission from the Jovian radiation belts. These data, merged with the ongoing NASA/JPL Jupiter Patrol, are being analyzed to determine the intensity of the synchrotron emission at the time of the spacecraft observations and throughout the C-JMOC observing period.

## **THE GAVRT SCIENCE EDUCATION PARTNERSHIP**

A large percentage of the Goldstone observations were conducted by middle-school and high-school students from classrooms across the United States. The students and their teachers are participants in the Goldstone-Apple Valley Radio Telescope (GAVRT) science education project, which is a partnership involving NASA, the Jet Propulsion Laboratory and the Lewis Center for Educational Research (LCER) in Apple Valley, CA. Working with the Lewis Center over the Internet, GAVRT students conduct remotely controlled radio astronomy observations using 34-m antennas at Goldstone. Students are actively involved in making radio astronomy observations with real science applications. They learn how to gather data and how to analyze the results. They work together learning team participation and problem solving skills. The staff of the LCER Operations Control Center in Apple Valley are "on line" with the GAVRT teachers and students throughout each observing session to support the students, answer questions and guide the team through the inevitable problems that arise in the 'real world' of observational research.

## Goldstone-Apple Valley Radio Telescope

Students conduct experiments using the Internet



**FIGURE 1:** Students carry out radio astronomy observations from their classrooms by connecting with the LCER Operations Control Center in Apple Valley. LCER staff at the control center support the session and monitor access to the radio telescope at Goldstone.

GAVRT teachers participate in several days of training when they join the team. They learn the basics of radio astronomy and practice operating the radio telescope by remote control first from the LCER Operations Control Center and later from their own classrooms. The GAVRT project provides curriculum and supports classroom implementation. GAVRT teachers can implement curriculum they receive from training or they can adapt their own lesson plans to fit the project. Opportunities exist within the curriculum to use it as a framework for integrated studies in Middle School. High Schools usually concentrate on the more complex science results featured in the curriculum

guide. The project curriculum is aligned with U.S. National Science Standards.

### CASSINI MAPS JUPITER AT 2.2 CM

Microwave measurements from the Cassini spacecraft were successfully carried out at a wavelength of 2.2 cm (13.8 GHz) the first week in January near the time of closest approach to Jupiter. The resulting data provide unique information on the highest energy electrons in the magnetosphere. Earth-based radio telescopes have difficulty measuring the synchrotron radiation at wavelengths this short because of the difficulty in separating atmospheric thermal emission from the synchrotron radiation,

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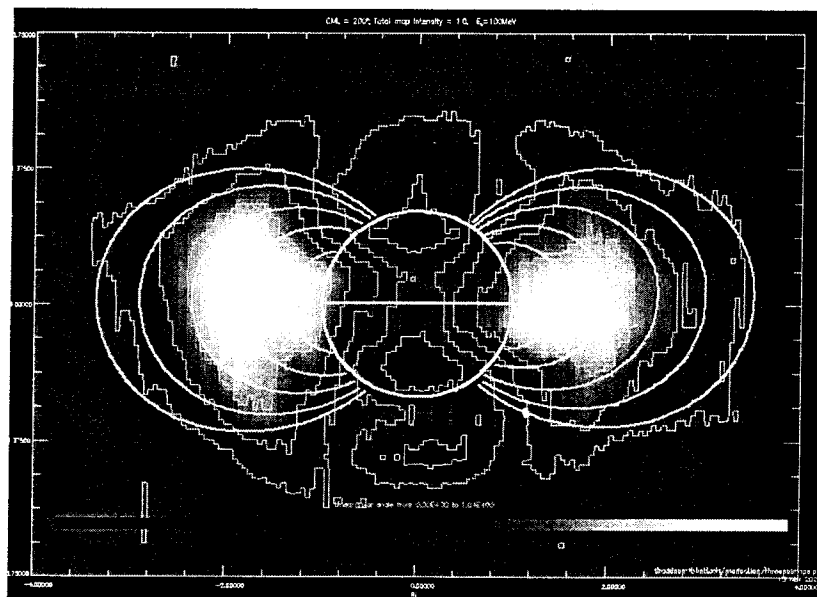
which becomes relatively weak at wavelengths shorter than  $\sim 6$  cm.

The 2.2-cm radiometer was used to produce ten maps covering a complete 10-hour rotation of Jupiter in horizontal polarization and another ten maps covering a second rotation in vertical polarization.

Synchrotron emission, although even weaker than anticipated, was clearly detected distinct from the thermal emission as evidenced by its polarization and spatial distribution. Preliminary maps of this radio frequency emission from Jupiter's radiation belts have been reported by Janssen et. al.<sup>1</sup>

and Bolton et. al.<sup>2</sup> Preliminary results are shown in Figure 2, which is a total intensity map of the 2.2 cm microwave emission from Jupiter's radiation belts integrated over two rotation periods. The emission peaks are clearly seen near the magnetic equator offset approximately two Jovian radii from the east and west limbs of the planet.

The twenty individual maps will soon be studied in detail as they are the first high resolution maps of Jupiter's synchrotron emission at 2.2 cm showing evidence of an ultra-relativistic ( $>40$  MeV) electrons in the Jovian radiation belts.



**FIGURE 2:** Microwave radio emission map of Jupiter’s radiation belts at 2.2-cm produced by the passive microwave radiometer built into the Cassini Radar Instrument.

## DSN AND GAVRT OBSERVATIONS

In addition to the space observations, Cassini-JMOC included ground-based observations of Jupiter's synchrotron radiation at a variety of wavelengths using the VLA (operating at 20 and 90 cm) and a combination of the GAVRT antenna and

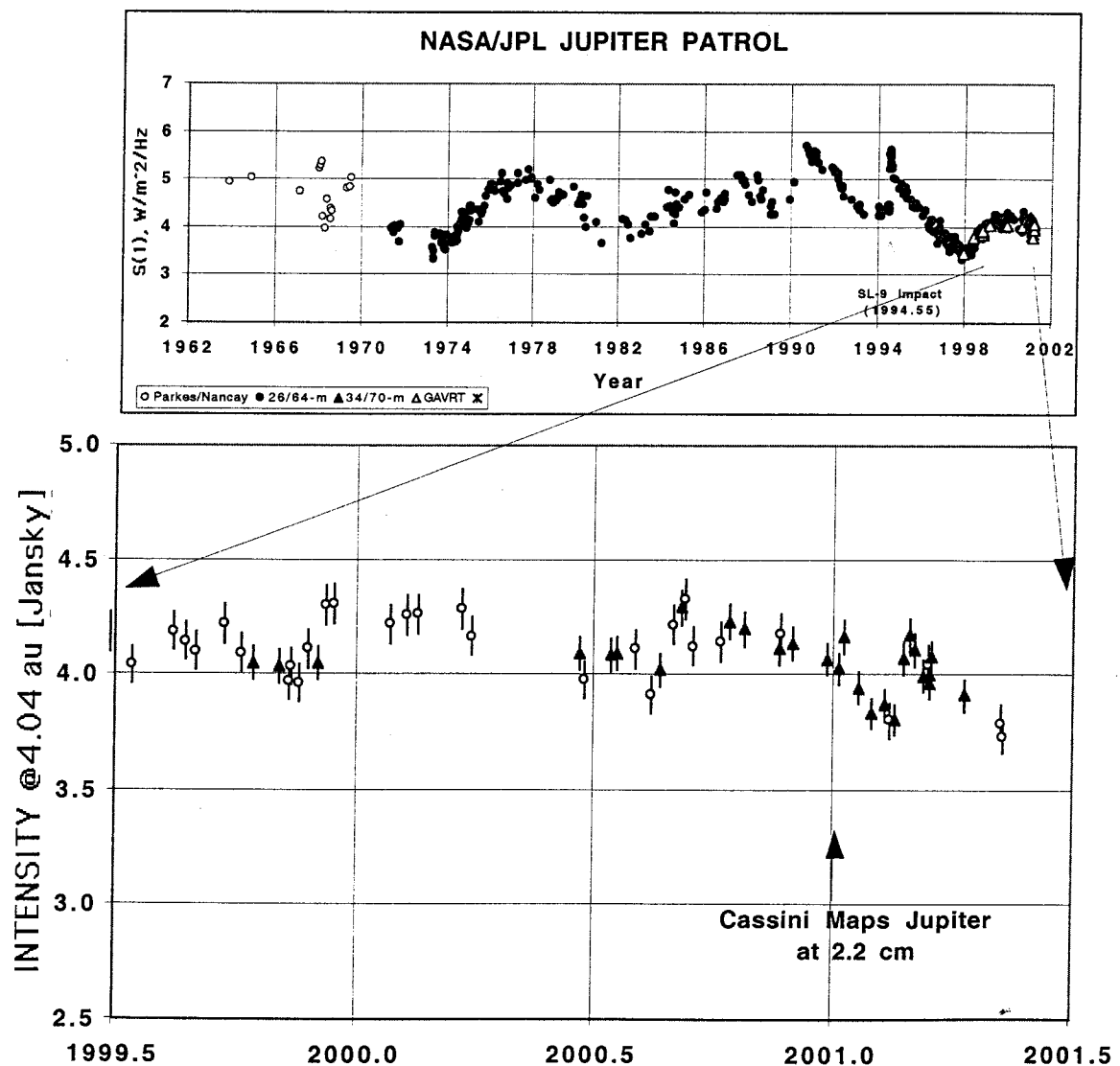
NASA's Deep Space Network operating at frequencies in the 13-cm, 3.5-cm, and 2.2-cm bands. We anticipate that by combining these data and incorporating previous ground based measurements (6, 13 and 20 cm), a considerably more complete understanding of the energy spectrum and

understanding of the energy spectrum and distribution of relativistic electrons trapped in Jupiter's radiation belts will be possible.

Jupiter's synchrotron emission is known to be time-variable and there is plausible evidence that the observed variations are correlated with changes in solar wind parameters, e.g., solar wind plasma density.<sup>3</sup> The Cassini encounter with Jupiter occurred as Solar activity is reaching the peak in the current eleven-year cycle. The last large-scale (>20 %) increase

in Jupiter's synchrotron flux density was observed in the winter of 1989-90, just about eleven years ago.

The GAVRT observations at 2.295 GHz (13-cm) were primarily made to monitor the time variations of the synchrotron emission from the radiation belts. The GAVRT data were merged with the ongoing NASA/JPL Jupiter Patrol to improve the sensitivity and time resolution of the resulting data. The results are shown in Figure 3.



**FIGURE 3:** Variations in the intensity of the microwave radio emission from Jupiter's radiation belts.

The upper panel in Figure 3 shows the thirty-year history of changes in the microwave radio emission from the radiation belts in the 11-13 cm bands. Changes up to thirty percent in the intensity of the microwave emission are clearly evident including the sudden outburst attributed to the impact of the Comet Shoemaker-Levy 9 in July of 1994. The lower panel is an enlarged view of the last two years of the data that includes the Cassini-JMOC observations. The open diamonds are NASA/JPL Jupiter Patrol observations made with DSN antennas. GAVRT team observations are represented by filled triangles. The relative 1-sigma uncertainty of the measurements is ~ two percent, which is about twice the size of the plotted data points. Note the excellent agreement between the two sets of data.

The DSN-GAVRT data suggest the total intensity of Jupiter's synchrotron emission may have increased by as much as ten percent in November 1999 and again the first week in August 2000. The intensity slowly decreased for the next six months, including the first week in January 2001 when Cassini mapped the radiation belts. Then around the third week of February, the intensity brightened approximately ten percent for a third time. The interpolated value of the synchrotron flux density on January 3 was  $4.02 \pm 0.08$  Jy.

These events of "modest" brightening appear to be intrinsic to Jupiter and not caused by systematic errors in calibration or by discrete background radio sources the planet passes during its twelve-year orbital path along the ecliptic. A systematic search for background sources in the NASA Extragalactic Database is routinely made during the data processing, and data affected by discrete background confusion

sources are edited from the data. The events noted above were free of this source of error. Evidence of short-term variations in Jupiter's synchrotron radio emission have been reported in the recent past.<sup>4,5,6</sup> In contrast to the sudden increase caused by the impacts of the Comet Shoemaker Levy 9,<sup>7</sup> these variations are of unexplained origin.

The DSN-GAVRT ground-based observations of Jupiter at 2.2 cm were made simultaneously with the spacecraft observations to transfer the accuracy of ground-based radio astronomy flux calibration to the Cassini radar receiver using Jupiter as a common reference source. Several standard radio sources and Venus were observed to calibrate the three radio telescopes that were used for the campaign. All of these sources were cross-calibrated relative to 3C295, a spatially compact, non-variable radio galaxy with an assumed flux density<sup>8,9</sup> of 1.78 Jy. System calibration sequences were performed throughout each observing session to remove sources of error caused by changes in system performance with antenna tracking in azimuth and elevation as well as the subtle changes in receiving system gain, stability and linearity. Although considerable effort was made to understand and mitigate the sources of systematic errors, there is additional work to be completed before the final absolutely-calibrated results will be ready to publish. The goal is to reduce the formal error to two percent (1-sigma) error and publish the results before the Cassini spacecraft reaches the Saturn system in 2004. The DSN-GAVRT data will be used as one of the calibration "benchmarks" for the Cassini Radar Instrument when it is used to study the thermal microwave emission from the surface of Titan, the rings of Saturn or the deep atmosphere of the planet.

## CONCLUSION

New information from the 2.2 cm maps from the Cassini spacecraft and the ground-based data from the VLA and DSN-GAVRT observations are being compared with results from the computational model<sup>10</sup> of the synchrotron radiation to improve current knowledge of the relativistic electron population within the inner Jovian magnetosphere. The unexpectedly low intensity of Jupiter's synchrotron emission observed with Cassini indicates that the energy spectrum of the electrons in the radiation belts is softer than current models assume. Consequently, to account for the synchrotron emission spectrum observed at wavelengths between 6-cm and 90-cm, the modification to the relative number of electrons at various energies must include a significant increase in the electron population < 20 MeV. Accurate knowledge of the spatial distribution and electron energy spectra of electrons in Jupiter's inner magnetosphere will be used by mission planners for future spacecraft that may pass through this extremely hazardous region of the solar system.

Improved computational models will also be used to search for plausible causes of the temporal variations in the microwave radio emission that have been observed for three decades as well as the short-term dip in the 13-cm total intensity that was observed from early January to ~20 February 2001. There is hope that the intensity fluctuation in January 2001 will reveal new insights about Jupiter's inner radiation belts when the DSN-GAVRT results are compared with the in situ particle and field measurements collected both the Galileo and Cassini spacecraft.

The educational purpose of the GAVRT project is to provide students and educators with curriculum vehicles that will promote science literacy, support a better understanding of the scientific community, and to provide the opportunity to collect real-time data with sophisticated science equipment through distance learning. It is a program designed to make the experience of scientific inquiry and discovery accessible to every American student.

In the words of three GAVRT educators: "We want our students to understand, but more than that, we want them to feel some part of the exhilaration that must have come with every scientific discovery. And yet, that is a challenge, because there remains, even in advanced science classes, a significant difference between classroom science and professional science. To give our students an experience in science that gives them insight into the world of professional science, we must, if only for a short time, give them access to the scientific community. We must give them a chance to be real scientists<sup>11</sup>."

The Cassini-JMOC experience involved approximately 2300 students and 41 teachers from twenty-six schools located in thirteen states. These students and teachers were valued members of the science team and their enthusiasm and dedication were critical to the success of the Cassini-JMOC project.

## Acknowledgments

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